Chapter 2
Operational Aspects of the Rocket Engine and the Test Facility

Design, construction and production are essential phases in the development of a rocket engine. As soon as the engine subcomponents are at a satisfactory development status, a complete engine, ready for operation, is examined on a test facility which is specially designed for this very engine. The aim of an engine test is to check and optimize the operational cycle of the engine and finally to confirm the readiness of the rocket engine for use on the launcher. When the rocket engine is used during flight, or when it is tested on the ground facility, the *operational aspects of the rocket engine* have to be considered. This means the engine dynamic behaviour during *start up*, during transit from one to another operational point, the characteristics at extreme operational points and during *shut down* of the engine.

The bench systems are adjusted to this *operational cycle*. The bench supplies the engine with propellant, secondary fluids (see Appendix J), electrical power and control signals. The operation on the facility also requires simulation of the conditions which will be met later on during actual flight. Furthermore, conditions have to be handled which have their origin in the engine operation itself (e.g. noise, exhaust jet, risks). In a wider sense, the safety of the engine environment is also part of the operational aspects as well as the measurement of the physical parameters. These measurements are necessary for the regulation, for monitoring of important engine parameters, for evaluation of the engine test and for evaluation of the engine behaviour during flight. Running the required bench systems and procedures to resolve these tasks is the subject of the *operational aspects of the test facility.*

An engine test can also be executed on the launch pad of the rocket (Fig. 2.1). In this case the test objective is the validation of the launch preparation related to the engine and its interaction with the stage (see Appendix E, Fig. E.1), including an ignition and a regular shut-down.

2.1 Propulsion Systems

The main components of a propulsion system of a rocket are the rocket engine, the fuel tank, the oxidiser tank and a pressurisation system. The first and second stages of a launcher basically consist of almost only the propulsion system. Even on satellites the propulsion system forms the major part of the weight and structure.

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Fig. 2.1 Ignition of a *Vulcain* engine on the launch pad during a *stage test* (Photo: CNES)

Fluids which are gaseous at ambient temperature but stored at low temperatures, below their boiling point, are called *cryogenic fluids* and rocket engines running on at least one cryogenic fluid (as fuel or oxidiser) are called *cryogenic engines* (Figs. 2.2 and 2.3). One of the first cryogenic rocket engines was used on the V2 rocket during World War II. The oxidiser of this engine was liquid oxygen (LOX).

LOX forms, together with liquid hydrogen (LH_2), a *high-level energy combination*. A typical specific impulse of such an engine is between 4,000 and 4,500 m/s. The *Pratt & Whitney RL-10,* developed in the 1950s was the first LOX/LH_2 engine used for spaceflight (Table 2.1).

Remark 2.1 *An aerospace scientist or engineer talking about the* ***engine cycle*** *normally means the cycle in which the engine produces its propellant (gas generator cycle, expander cycle, etc.), the* ***propulsion cycle****. In thermodynamics, the engine cycle is very close to the* ***Joule*** *cycle, and we could also talk about the life cycle of an engine type (design, production, test, flight service). The focus in this book is the* ***test cycle*** *or* ***operational cycle.*** *On the facility the engine goes several times through the cycle of pre-tests, final preparation, hot run and post-tests. On the launcher this cycle only happens once for an expendable engine.*

The special properties of a cryogenic fluid (see Appendix J) have to be considered within the operational aspects, particularly when it comes to preparation of a hot run. Vessels and lines need sufficient insulation, the feed system has to be free of pollution and a chill down phase is required before the hot run. The purging and venting of the rocket engine and the feed system starts immediately after shut-down and a cryogenic fluid must not be trapped in any of the line segments or engine components.

2.2 Test Facilities

To launch rockets just for test purposes or even in the development phase is history, at least for large launchers. A rocket engine dedicated for use on a launcher definitely needs its maturity for flight. The investment to lift a payload into orbit is in the region of some hundred million Euros and therefore, from first use on,

Table 2.1 Rocket engines running on LH_2/LOX as a fuel/oxidiser combination [8]

Engine	Manufacturer	Origin	Propulsion cycle	Thrust (kN)	Chamber pressure (bar)	Mass (kg)	Spec. impulse (Ns/kg)	Area ratio	Mixture ratio
Vulcain 2	SNECMA	France	Gas generator cycle	1,340	115	2,100	4,228	60	6.1
Vinci	SNECMA	France	Expander cycle	180	60	550	4,562	240	5.8
HM7B	SNECMA	France	Expander cycle	64.8	37	165	4,375	83.1	5
RL-10	Pratt & Whitney	USA	Expander cycle	66.7	20	135	4,248	40	5.9
SSME	Rocketdyne	USA	Staged combustion	2,094	207	3,393	4,434	69	6
LE-7A	JAXA	Japan	Staged combustion	1,096	121	1,700	4,316	52	5.9
RD-0120	KBChA	Russia	Staged combustion	1,962	219	3,450	4,464	87.5	6
RL-60	Rocketdyne	USA	Expander cycle	3,315	97	6,604	4,022	21.5	6

Fig. 2.2 Upper stage engine SNECMA HM7 (Photo: SNECMA)

Fig. 2.3 Space shuttle main engine, Rocketdyne (Photo: NASA)

a very high reliability of the propulsion system is mandatory. Unfortunately not all flight conditions can be simulated on a test facility and therefore a maiden flight will always remain a test flight. The hardware (engine dedicated for flight) and software (operational cycle and control programs) have to prove this high level of reliability on the test facility. On the facility the operational cycle is optimized, the engine is brought to maturity and during flight the engine finds its real application. In Europe's *Ariane* program an engine was normally tested twice, the second test being a precise rehearsal of the planned performance during flight. Before the first launch of an *Ariane 5*, its main engine *Vulcain* was tested 135 times on the facility *P5* and about the same number of tests was performed on the almost identical facility *PF50* in Vernon, France.

The dimension and design of a test facility for rocket engines consequently follows the specimen and type of the requested tests. The size factor is easily dealt with, a small engine normally being tested on a small test rig, which is separated from the adjacent control desk by just a concrete wall. Large rocket engines are installed in large test facilities (Fig. 2.4), equipped with cranes, lifts, etc., and the control room is some 100 m away, in a bunker with several floors. The layout of the run tanks depends on the fuel/oxidiser combination. On a test facility for a cryogenic rocket engine, double wall, vacuum insulated tanks are used. The size of the tanks is matched to the consumption of the engine and to the requested test duration, the test duration again following the burn time of the engine during flight.

Before large rocket engines are tested in the completed configuration (*engine level test*), tests with single components of the engine are performed (*component level test*). The dimension of a facility for component testing can be large if we consider, e.g. that a test of a hydrogen turbo pump involves the same mass flow as on the complete rocket engine (Fig. 2.5). Hence the fuel supply has the same dimensions and the same safety systems are installed. The effort to set up the facility can be partially reduced if the demanded test duration is smaller than the flight duration or if the engine is not tested at full thrust.

The test facility has, besides the test bench and the control room, significant subfacilities (Fig. 2.6). A very important sub-facility is the *altitude facility*. Engine tests under altitude conditions require a vacuum chamber, in which the engine is tested at low pressures equivalent to the pressures at high altitudes. Steam driven ejectors, powered by steam generators or steam vessels, are used to evacuate the vacuum chamber (Fig. 5.24).

Fig. 2.4 Test facility *P5* at German Aerospace Center (DLR) in Lampoldshausen for testing the *Vulcain* engine at sea level conditions (Photo: DLR)

Fig. 2.5 Component test facility for the LH_2 turbo pump of the *Vulcain* engine at SNECMA, Vernon [14] (Photo: SNECMA)

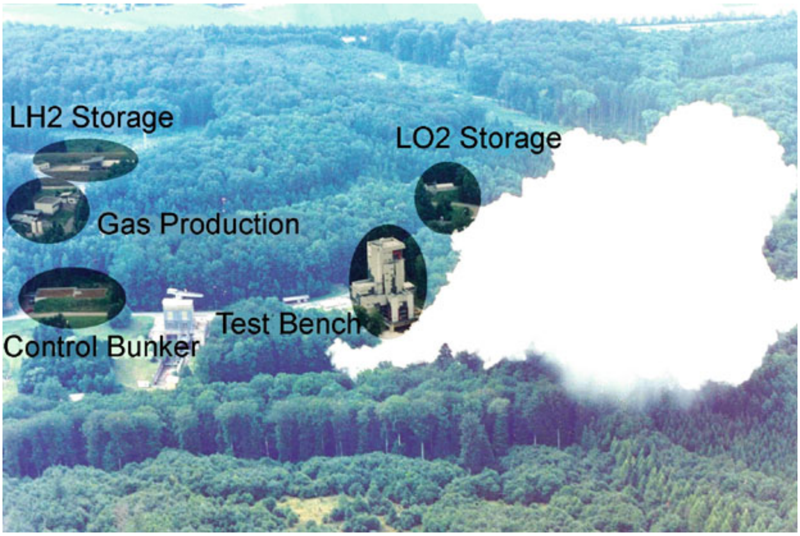

Fig. 2.6 Sub-facilities of the large test facility *P5* for the *Vulcain* engine at DLR, Lampoldshausen (Photo: DLR)